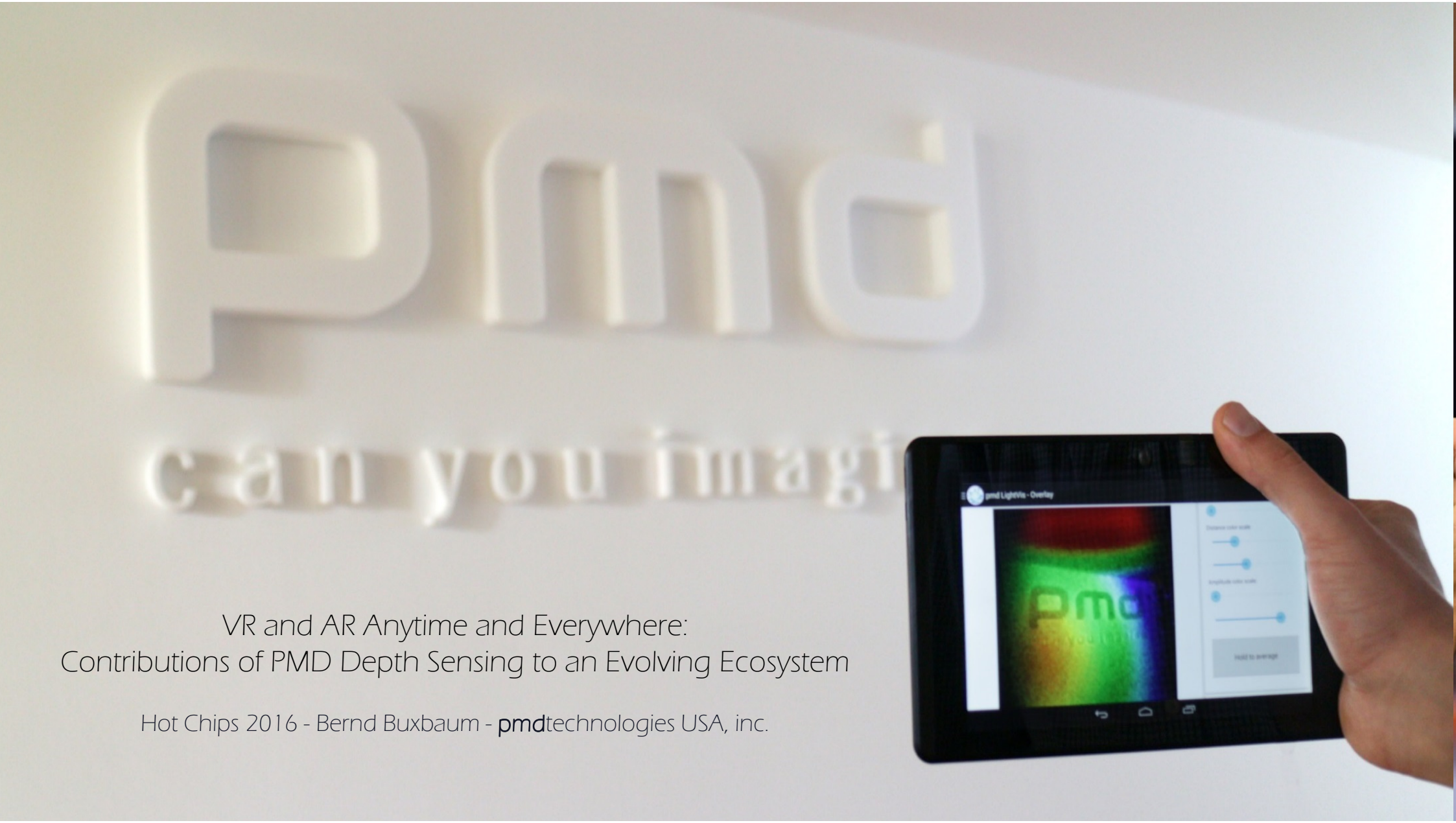


VR and AR Anytime and Everywhere: Contributions of PMD Depth Sensing to an Evolving Ecosystem

Hot Chips 2016 - Bernd Buxbaum - pmdtechnologies USA, inc.


pmd
can you imagine
pmd
„It‘s a brave new world“
Barack Obama, HMI 2016@ifm booth
pmd
abcNEWS
.com

ifm <–> pmd

pmd was founded **2002**

Fabless IC business, range finding, 3D imaging
Automation/Robotics, Consumer, Automotive
100 employees in Siegen (HQ) & Dresden/Germany, San Jose/USA

Non-public **stock company** (ifm as major shareholder)

ifm was founded **1969**

Worldwide Leader in Sensors & Control Systems
Automation, Robotics, Automotive - **SAP** Partner, **Industry 4.0**
6000 employees in over 70 countries

Privately owned in 2nd generation

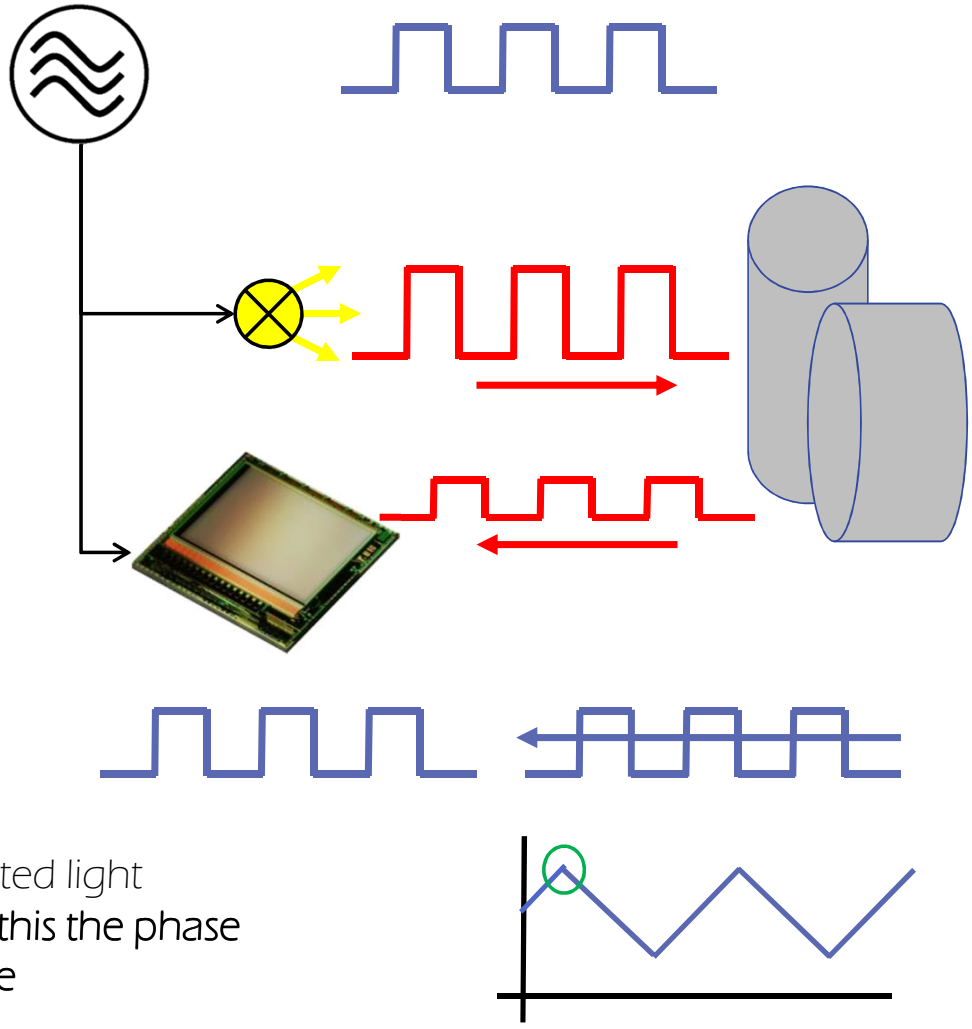
Time-of-Flight ("indirect" ToF)

Electrical modulation signal

Emission of electrically modulated light

Detection of the reflected modulated light

Convolution of reflected modulated and the emitted light

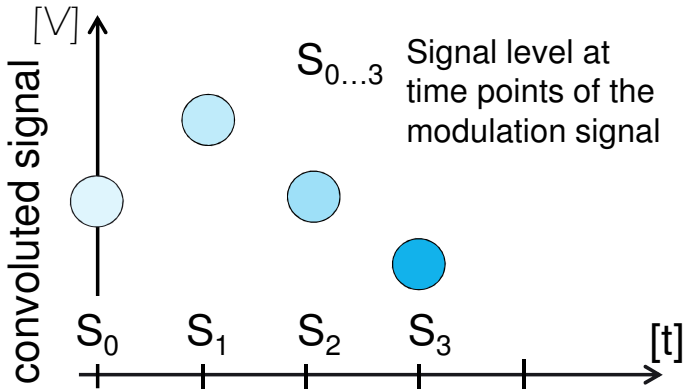


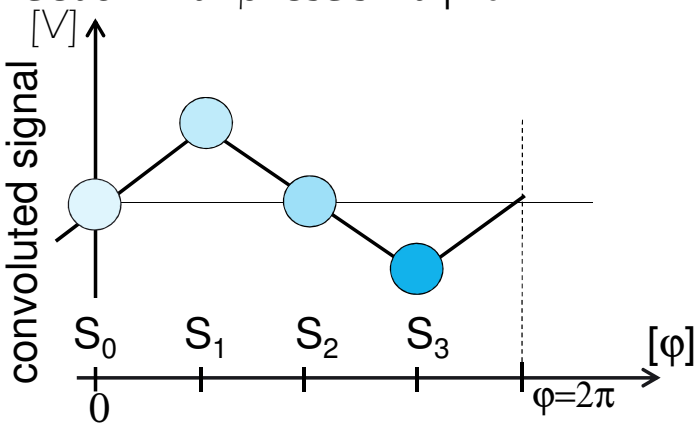
⇒ Correlation of the emitted and the reflected light

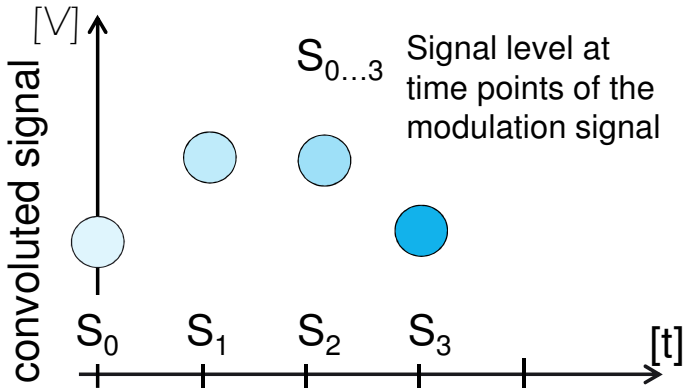
⇒ Goal: Determine where the "peak" is → this the phase delay, which corresponds to the distance

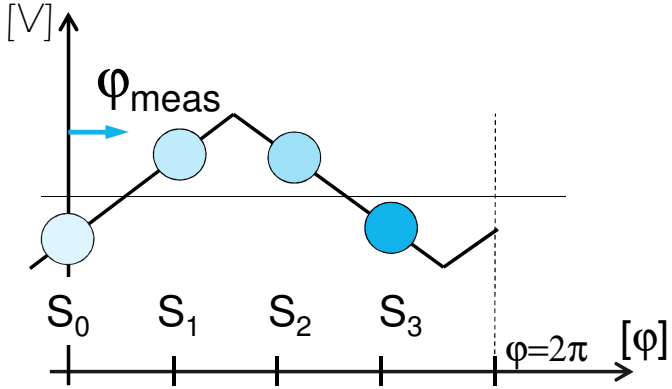
How to determine the peak of the correlation

	Raw data measurements	Fitting of autocorrelation function
Time of flight = 0	sampled signals in one pmd pixel	autocorrelation with phase shift $\varphi=0$
Time of flight > 0	sampled signal in one pmd pixel	autocorrelation with phase shift $\varphi > 0$



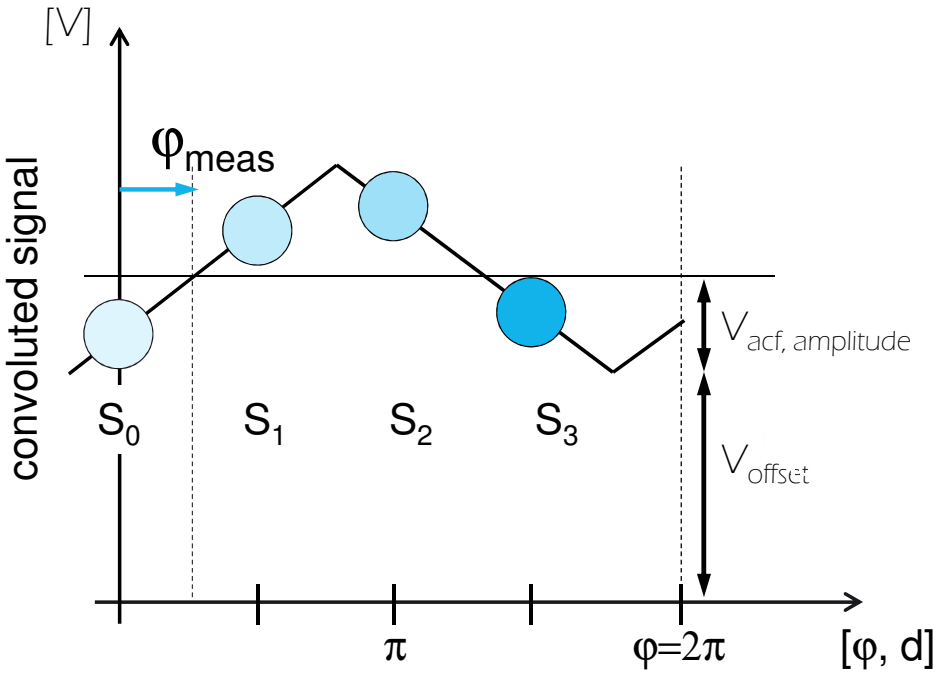






Information derived in SW from raw data

On chip



$S_{0...3}$ measurement points of signal amplitude

—— distance @ φ>0, d ~ φ

On host system/AP

Distance information

$$\varphi_{meas} = \arctan\frac{S_3 - S_1}{S_0 - S_2}$$

Depth map

Amplitude information

$$V_{acf,ampl} \propto \sqrt{(S_3 - S_1)^2 + (S_0 - S_2)^2}$$

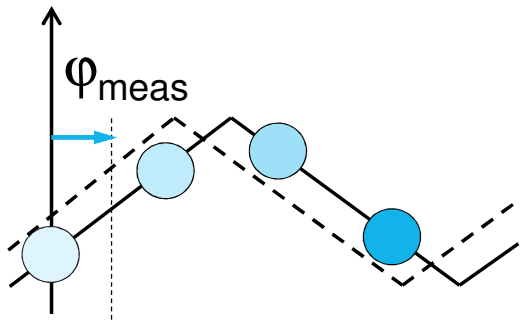
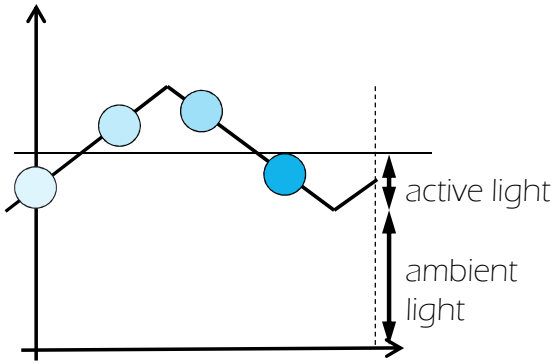
2D b/w image based on modulated light

Intensity information

$$V_{offset}$$

2D b/w image based on ambient light

pmd: Advantages vs. side effects

Unique behavior	Advantage	Side effect
Sequential sampling of autocorrelation function 	real measured 3D value out of each pixel ⇒ no need of base line ⇒ no need of high computation power ⇒ calculation on frequency level, no pulsed signals	distance image requires 4 measurements over time ⇒ motion blur occurs ⇒ motion artefacts can be detected by algorithms
Usage of active, modulated illumination 	active light extracted on signal level ⇒ distance information descrambled of background light ⇒ stable 2D image without background light influence	3D measurement is based on active light ⇒ for far range sensing amplitude of active light needs to be adjusted

Options to optimize pmd on signal level

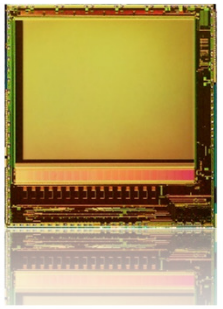
Precondition:

Given is a signal quality, how are the options to optimize the system?

Physical options	Double range on **low (active and ambient) light** conditions	Double range on **normal light** conditions	Double range on **strong background light** conditions	Proposals for technical solutions
Optical aperture	F-number * $\frac{1}{2}$	F-number * $\frac{1}{2}$	F-number * $\frac{1}{4}$	bigger lenses
Modulation frequency	f_{mod} * 2	f_{mod} * 2	f_{mod} * 4	higher modulation
Signal amplitude	P_{act} * 4	P_{act} * 4	P_{act} * 4	more light sources
Integration time	T_{int} * 4	T_{int} * 4	T_{int} * 16	longer meas. cycle
background light	N/A	N/A	$P_{background}$ * $\frac{1}{16}$	narrow optical filter

Note: further options are possible on 3D algorithm level

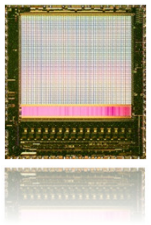
Scalability: pmd chips



100k Imager

SoP Q1/2015

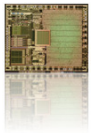
60 mm^2 – Bare Die



38k Imager

SoP Q3/2016

28 mm^2 – Bare Die



1D Sensor

SoP Q2/2016

12 mm^2 - CSP

Scalability: Same imager, different cameras

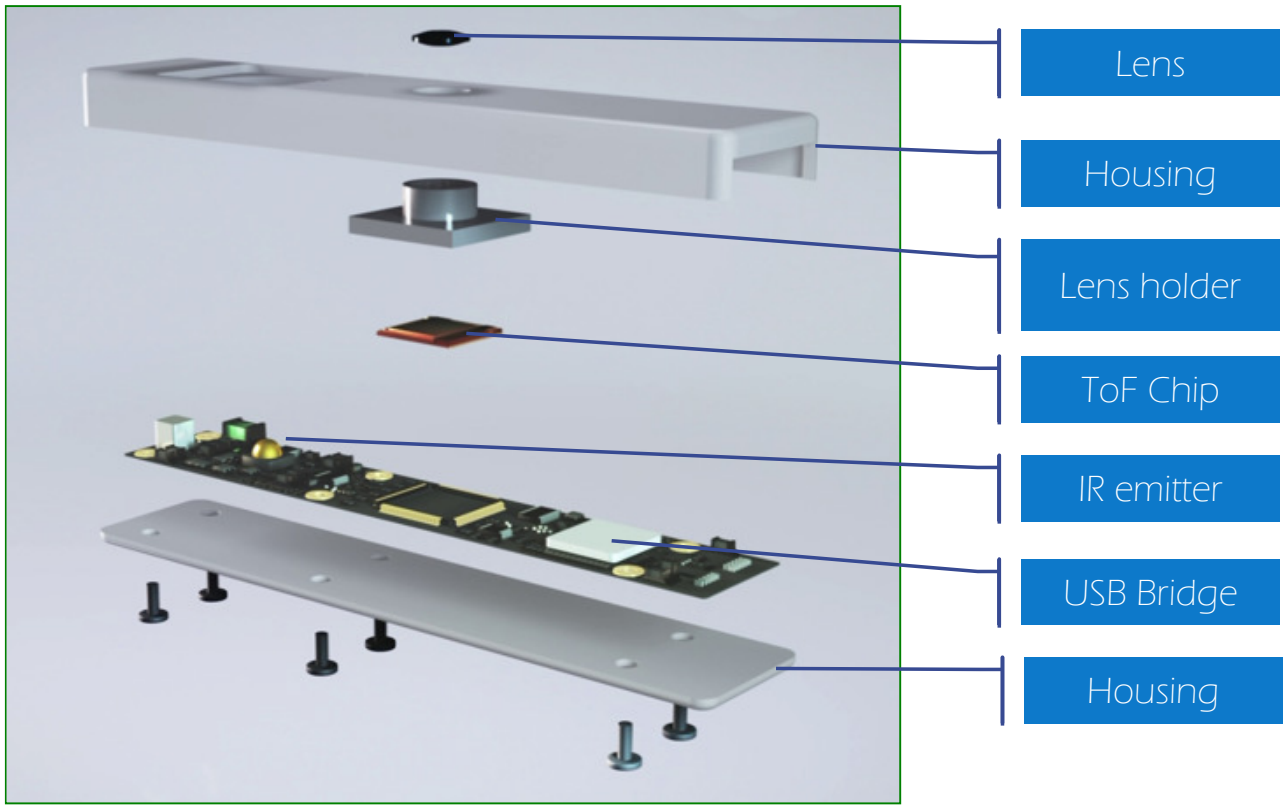
pmd[vision]® MiniCam

Illumination	4 LEDs
$f_{Modulation}$	30 MHz
Working range	up to 15m
Fps	up to 35 fps
FoV	60° x 45°
Pixel	352 x 288
Size	45mmx45mmx80mm

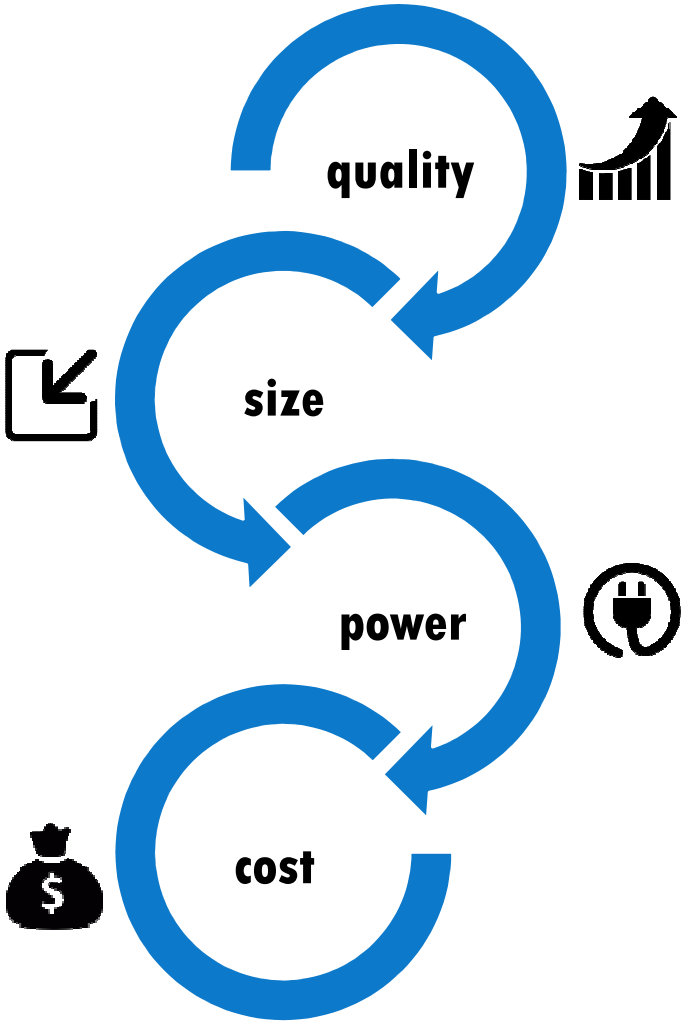
CamBoard pico flexx

Illumination	1 VCSEL
$f_{Modulation}$	80 MHz
Working range	up to 4m
Fps	up to 45
FoV	60° x 45°
Pixel	224x172
Size	86mmx17mmx7.25mm

What's inside a pmd camera and how it scales

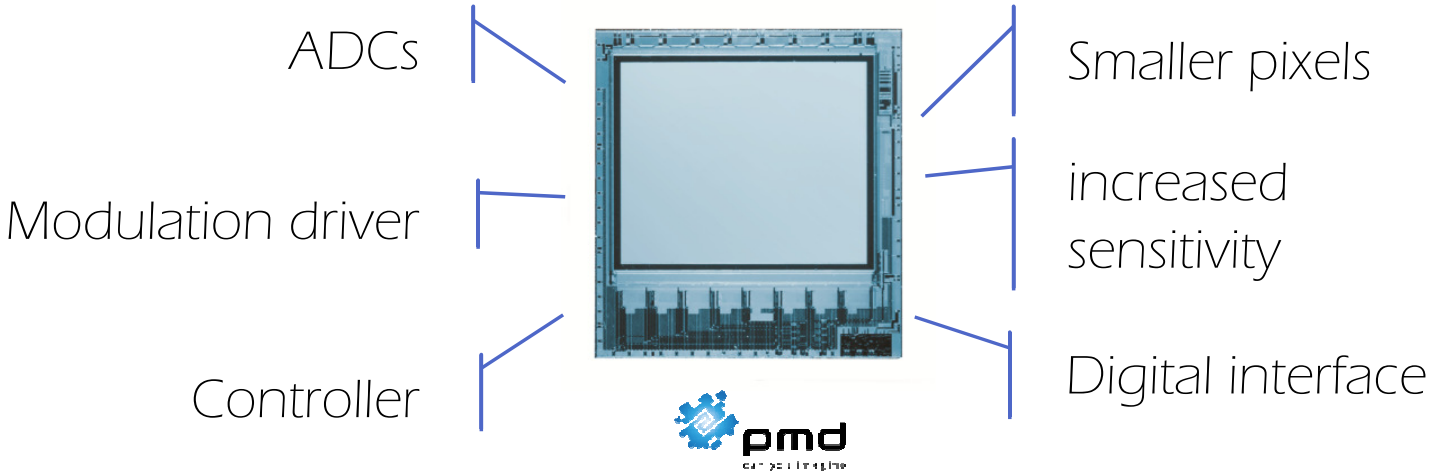


Robust – scalable - tailored



Scaling towards integrated depth sensing

Step 1: optimize the chip



Scaling towards integrated depth sensing

Step 2: Optimize the lens

- Reduce z-height
- Make it fast (low f#)
- Optimize FoV and resolution
- Reduce vignetting & stray light

Lens v0.0

Jan 2013
160x120px
5.2mm

Lens v1.0

Jun 2013
160x120px
3.6mm

Lens v2.0

Jan 2015
224x172px
4.13mm

Scaling towards integrated depth sensing



	CamBoard pico	CamBoard pico^{S}	CamBoard pico flexx
Objektiv height	5.2 mm	3.6 mm	4.13 mm
f-number	1.46	1.63	1.58
FoV (H)	90°	82°	60°
			
Camera height	8.5 mm	6 mm	7.25 mm
#Pixels	160x120	160x120	224x172

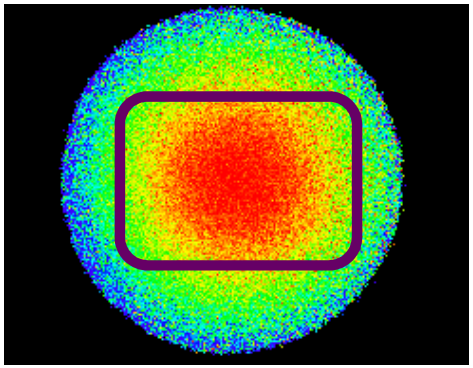


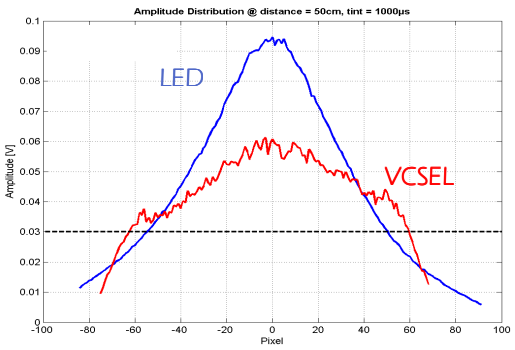

Scaling towards integrated depth sensing

Step 3: Optimize the illumination

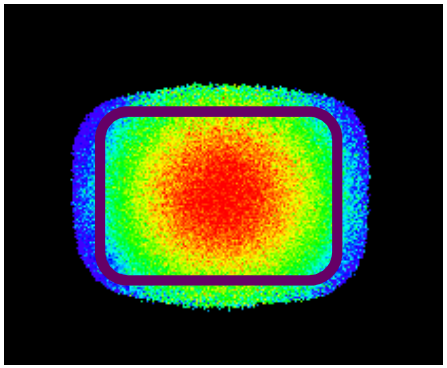
From LED to VCSEL (vertical-cavity surface-emitting laser)

LED
30MHz

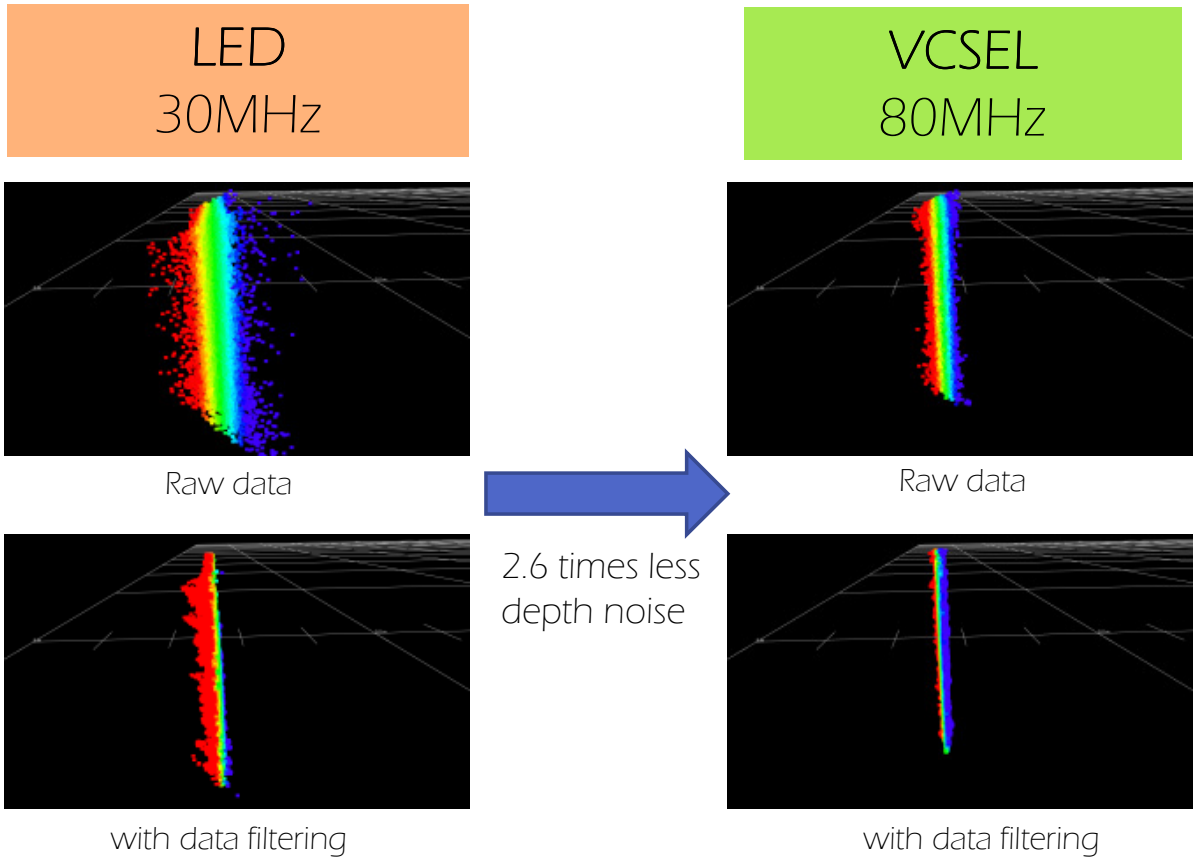




VCSEL
80MHz



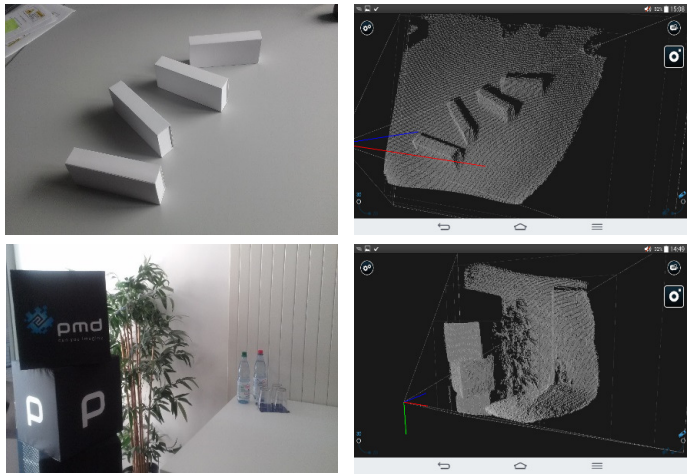
Scaling towards integrated depth sensing



Scene: Wall, 30 cm distance – side view

Use cases enabled by devices

[Frontend and Project Tango Qualcomm/Google mobile development kit as shown at Google I/O 2015]



[CamBoard pico flexx and example 3D point clouds; CamBoard pico flexx is shipping to developers]

Can you imagine?

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